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# Evaluation of Photosynthetic Roles of Different Canopy Strata and Capitulum on Seed Yield and its Components of Spring Safflower (*Carthamus tinctorius* L.)[#]

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ABSTRACT

The main source of seed filling results from the photosynthesis of the green tissue closest to the seed sinks in the capitula. To evaluate the role of different leaf strata and capitula in seed yield and its components of Safflower genotypes, a field study was performed as a factorial experiment based on RCBD in 3 replicates in East Azarbaijan Agricultural and Natural Resources Research and Education Center in 2008. The used factors in this experiment were: two Safflower genotypes including (Mahalli Esfahan and Goldasht) and defoliation in five levels: defoliation of plants in lower 1/3, middle 1/3, upper 1/3 of the stem, capitulum covered with aluminum paper and control (without defoliation). The results showed that defoliation did not affect plant height and number of pods. But, there was a highly significant difference between strata in terms of number of seeds per pod, number of seeds per plant, 1000 seeds weight, oil percentage and oil yield. The interaction of genotype×strata treatments in seeds yield and harvest index was significant. Among the defoliation treatment levels in both genotypes, the highest decrease in the seed yield compared to the control were observed in the upper 1/3 defoliation levels, whereas the lowest decrease was observed in the lower 1/3 defoliation level. The rate of seed yield reduction in Mahalli Esfahan was higher than Goldasht. The change in Goldasht seed yield was mostly due to changes in the number of seeds per plant and the number of seeds in the head. In addition, net photosynthesis, strata leaf area, and photosynthesis contribution of the upper strata compared to the lower ones were higher, and removal of the upper strata had the highest effect on seed yield through the reduction in the total photosynthesis of the whole plant. Also, covering the capitulum caused a significant decrease in the seed yield. So, head photosynthesis has a major contribution to Safflower seed yield.

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## Introduction

Oilseeds after cereals comprise second place in the world's food production (Palchamy et al., 2020). Safflower has been introduced as a cultivar of both edible oils suitable for consumption by humans and livestock also use as biodiesel. Meanwhile, safflower oil is gaining important attention amount oil seeds (Dordas and Sioulas, 2008). Regarding the photosynthesis process, sink-to-source photosynthetic activity is attributed to photosynthetic substance consumption in most field crops (Querix et al., 2001). A recent study pointed out a relationship between sink and source affecting total yield which would have reduced in terms of appearance imbalance in the sink and sources functions, indeed (Khan et al., 2002; Zhu et al., 2010). Other obstacle phenomena like a shadow or defoliations utilizing labelled CO2 have been shown to compensate for the losses in photosynthetic growth (Erbas and Baydar, 2007). Leaf compensatory and shadowing reduce between 12,4% and 14,2% (Ehsanzade and Mahmudieh, 2004) growth and yield eventually. Moreover, from 29% up to 46,1% in seed weight in pods affected by the emphasized issue (Farid and Ehsanzade, 2006) with modified photosynthetic capacity has already been reported by local studies in Iran (Ehsanzade and Mahmudieh, 2004). Studies on the effects of leaves removal on yield and quantitative traits in crops were shown that defoliation reduces yield (Zhu et al., 2010) and oil content in oilseed crops (Abdi et al., 2007). So far, no written information has been provided on the photosynthetic contribution of leaf strata and different components of safflower plants in the formation of yield

and its components. Therefore, the present study was designed and conducted to investigate the contribution of the photosynthetic rate of different strata on grain yield and its components in two different safflower genotypes. One of the limitations of safflower cultivation is its low function compared to the time it takes for the plant to form. Therefore, examining and identifying the contribution of each of the different leaf and inflorescence levels in the filling of seeds will help plant breeders to develop those parts in new cultivars while increasing function, to achieve acceptable production during the growth period of this plant. Also, by identifying the contribution of different leaf segments in grain filling, better decisions can be made about increasing and decreasing density.

## Materials and Methods

The experiment was carried out at the experimental station of the East Azerbaijan Agricultural Research Centre nearby the city of Tabriz at 460 3`E and 370 58`N and 1320m altitude. The experimental field contains loam soil features among 0.06% nitrogen as well as phosphate, potassium 28 and 320mg/kg soil respectively. The Soil lab. was sent to analyse and determined the pH of 8.1 for the experimental soil (Table 1).

Table 1. Characteristics of the soil (0 to 30 cm depth)

| *Soil texture* | *loam* |
|---|---|
| Sand (%) | 42 |
| Silt (%) | 28 |
| Clay (%) | 30 |
| K (mg/kg) | 320 |
| P (mg/kg) | 28 |
| N (mg/kg) | 0.06 |
| Organic carbon (%) | 0.72 |
| pH | 8.1 |
| EC (dS/m) | 2.6 |

The metrological data showed an annual record for local temperature as 11°C, including a maximum annual temperature of 16.5°C, minimum annual temperature of 2.78°C, and 273.1mm annual prescription, on average. For biological materials, using two safflower cv. Goldasht and Local Isfahan were planted in April 2008, with 0.5 m between rows, 0.1m between planted seeds, 0.04 m depth, and 5 seeds per meter of row. One week after germination the density of plants was equalized to 20 per meter of row. Yield compounds and certain agronomical features measurements were applied in experimental plots which included 10 plots in four rows of plants; the two outer rows (0.5 m) were considered borders rows though two central lines were divided into six sections of 0.5 m each and another of 4 m of row. Seeds were sown in (3×2) 6 $m^2$ plots at the experimental field of the research center. For plant nutrients supplying uniform basal application of nitrogen (N), phosphorus (P), and potassium (K) with 15 $g/m^2$ ammonium phosphate, 10 $g/m^2$ urea was employed Therefore, plots fertilization was applied with ammonium phosphate before sowing the seeds and urea was fertilized at the stage of 12 leaves and before flowering stages ordinary. At the time of seedling establishment, a uniform population of 12 plants/$m^2$ was maintained after weeds were controlled manually. Defoliation treatments were arranged in a randomized block design. In this experiment two local genotypes (Mahalli Isfahan and Goldasht) were used.

Treatments consisted of five defoliation levels (Lower 1/3, middle 1/3, upper 1/3 defoliation of plant, capitulum covered with aluminium paper, and control (without defoliation)). Remove the leaves that began at the beginning of flowering. For this purpose, the height of the plant is divided into three equal parts, and the removal of different strata was done manually according to it. To prevent photosynthesis of brackets around pods, they Were covered by aluminium foil. After removing the leaves from each plot, 3 plants were randomly selected and three specific leaves were sampled from the remaining strata in each plot. After that their leaf area was determined by using a digital leaf area meter (Leaf Area Meter; model, C47; ACDE, Japan). After removing the leaves, at the beginning of flowering, from each plot 3 plants were randomly selected and net photosynthesis (μmol $CO2.m^{-2}.s^{-1}$) was measured from a specific leaf on each stratum by (IRGA, model: LCA4, ADC Biosientific Ltd. UK). It was measured at light intensity saturating between 11:00 and 12:00 h. Photosynthesis of each stratum and photosynthesis the contribution of each stratum was calculated from the following formulas; (Photosynthesis of each floor = Leaf Area of each floor×Net Photosynthesis) and (photosynthesis contribution of each strata= Photosynthesis of specific strata/Total photosynthesis of all three strata×100). Lab analyses were conducted to measure the following factors: number of pods per plant, number of seeds per pod, number of seeds per plant, the weight of 1000 seeds per pod and, harvest index as well as oil rate percentage using (SOX406 Fat Analyser, Hanon Instruments). Oil yield was figured out of oil percentage in yield per hectare.

A randomized complete block design was used in this study. Data were analysed by an analyses variance (ANOVA) using MSTAT-C to test the significance of the main effects. Mean separation on data was applied using LSD multiple rage tests. Terms were considered significant at $P<0.01$. For features (factors) regression calculation used SPSS vs. 15 and for graphic illustration Excell programs.

## Results and Discussion

According to the results in Table 2, the interaction of genotype×strata treatments in the Leaf area of strata was significant in the treatment of control and greater values of this parameter were observed in 1/3 upper strata in Mahalli İsfahan Genotype (0.13 $m^2$) and the lowest was observed in the middle 1/3 strata in Goldasht genotype (0.04 $m^2$). In Mahalli Isfahan, the leaf area of the lower and middle strata was 50% and 58% lower than the upper strata respectively. Also in Goldasht, the leaf area of the lower and middle strata was 28.6% and 42.9% lower than the upper strata respectively. This indicates that the leaf area of the upper strata was more than others in both genotypes and Mahalli Isfahan has more leaf area in all strata than the Goldasht genotype. Leafe area of Goldasht relative to Mahalli Isfahan in lower, middle and, upper strata was lower at 16.7%, 20% and, 14.7% respectively. Genotypes did not show a significant difference in terms of Net photosynthesis but the net photosynthesis of different strata had a significant difference ($P<0.01$) (Table 2). The upper 1/3 strata had more

Net photosynthetic rate (4.4 µmol $CO^2.m^{-2}.s^{-1}$) and the lower strata had a lower Net photosynthetic rate (1.7 µmol $CO^2.m^{-2}.s^{-1}$) in comparison to other strata.

At the same time, the photosynthetic contribution of different strata in Mahalli Isfahan in the upper strata was much higher than in Goldasht. The reason was that the leaf area was mostly in Mahalli Isfahan. Despite the leaf area of most middle and lower strata of Mahalli Isfahan, the photosynthetic contributions of these two arches in this genotype were less than Goldasht. Because in Mahhali Isfahan, the leaf area of most of the upper strata prevents light from penetrating the lower strata and does not allow the lower leaves to reach the point of light compensation. The net photosynthesis rate of the lower and middle floors was 61.4% and 41% lower than the upper floors respectively. This may be due to the young leaves on the upper strata receiving more light by them.

The interaction of genotype×strata treatments in Photosynthesis of Stratas was significant in the treatment of control. The greater values of this parameter were observed in 1/3 upper strata in Mahalli İsfahan Genotype (0.53 µmol $CO^2.m^{-2}.s^{-1}$) and the lower were observed in the lower 1/3 strara in Goldasht genotype (0.09 µmol $CO^2.m^{-2}.s^{-1}$). In Mahalli Isfahan, photosynthesis of the lower and middle strata was 81% and 75.5% lower than the upper strata, respectively. Also in Goldasht, photosynthesis of the lower and middle strata was 72.7% and 63.6% less than the upper strata, respectively. This indicates the most rate of photosynthesis of upper strata in both genotypes. On the other hand, in all strata, the photosynthesis of Mahalli Isfahan was more than Goldasht. So that in the lower, middle, and upper strata, the photosynthesis of Goldasht was 10%, 7.7%, and 20% less than the Mahalli Isfahan, respectively.

According to the results in Table 3, the interaction of genotype×strata treatments in the Leaf area of strata was significant in the treatment of 1⁄3 lower leaf removal and greater values of this parameter were observed in 1/3 upper strata in Mahalli İsfahan Genotype (0.12 $m^2$) and the lowest was observed in the middle 1/3 strata in Goldasht genotype (0.04 $m^2$). Also, after removing the leaf, the leaf area of the remaining stratas did not change compared to the control. Since defoliation treatment was applied after the plant entered the reproductive stage and the end of vegetative growth, defoliation did not affect the plant leaf area.

Genotypes did not show a significant difference in terms of Net photosynthesis but the net photosynthesis of different strata had a significant difference (P<0.01) (Table 3). The upper 1/3 strata had more Net photosynthetic rate (7.58 µmol $CO^2.m^{-2}.s^{-1}$) and the middle strata had a lower Net photosynthetic rate (3.12 µmol $CO^2.m^{-2}.s^{-1}$) in comparison to other strata. In other words, the net photosynthesis rate of the middle strata was 58.8% lower than the upper strata. This may be due to the young leaves on the upper, receiving more light and high photosynthetic activity by them. The interaction of genotype×strata treatments in Photosynthesis of upper and middle Stratas after defoliation was significant in the treatment of 1⁄3 lower leaf removal (P<0.01) (Table 3).

The greater values of this parameter were observed in 1/3 upper strata in Mahalli Isfahan Genotype (0.95 µmol $CO^2.m^{-2}.s^{-1}$) and the lowest was observed in the middle 1/3 strata in both genotypes. In Mahalli Isfahan and Goldasht, photosynthesis of middle strata was 84.2% and 66% less than the upper strata respectively. After defoliation of 1/3 lower strata, the amount of photosynthesis in the middle and upper strata compared to the control was increased by 16.7% and 42%, respectively. Increased photosynthesis following leaf removal has been reported in several studies (Turnbull et al., 2007; Handa et al., 2005; Elfadl and Luukkanen, 2003). This may happen due to chemical changes in the leaves, water relations, and plant nutrient rate (Turnbull et al, 2007). Some studies have also reported an increase in photosynthesis after defoliation due to increased nitrogen in the remaining leaves (Lavigne et al., 2001). One mechanism for interpreting the increase in plant nitrogen rate following defoliation is the increase in nitrogen in photosynthetic structures as well as chlorophyll b and Rubisco (Evans, 1989).

Table 2. Analysis table of photosynthesis leaf stratas in two safflower genotypes in treatment without leaf removal

| Source of Variation | DF | LAS | NP | PS | PCDS |
|---|---|---|---|---|---|
| Replicates | 2 | $0.00005^{ns}$ | $0.012^{ns}$ | $0.001^{ns}$ | $0^{ns}$ |
| Genotyp | 1 | $0.0026^{**}$ | $0.236^{ns}$ | $0.023^{**}$ | $0^{ns}$ |
| Strata | 2 | $0.0043^{**}$ | $11.595^{**}$ | $0.201^{**}$ | $4512.338^{**}$ |
| Genotyp × strata | 2 | $0.00081^{**}$ | $0.005^{ns}$ | $0.019^{**}$ | $103.727^{**}$ |
| Error | 10 | 0.00003 | 0.125 | 0.0002 | 5.180 |
| Coefficient of Variation (%) | | 10.07 | 12.15 | 6.77 | 6.83 |

DF: Degrees of freedom; LAS: Leaf Area of Stratas; NP: Net Photosynthesis; PS: Photosynthesis of Stratas; PCDS: Photosynthetic contribution of different Stratas; ** = Significant at 1% level, * = significant at 5% level, ns= Not significant

Table 3. Analysis table of photosynthesis Upper and middle stratas in two safflower genotypes in treatment 1⁄3 lower leaf removal

| Source of Variation | DF | LAS | NPM | PMS |
|---|---|---|---|---|
| Replicates | 2 | $0.00001^{ns}$ | $0.218^{ns}$ | $0^{ns}$ |
| Genotyp | 1 | $0.0023^{**}$ | $0.002^{ns}$ | $0.140^{**}$ |
| Strata | 1 | $0.0057^{**}$ | $59.764^{**}$ | $0.957^{**}$ |
| Genotyp × strata | 1 | $0.00018^{**}$ | $0.791^{ns}$ | $0.161^{**}$ |
| Error | 6 | 0.000006 | 0.0408 | 0.003 |
| Coefficient of Variation (%) | | 3.30 | 11.94 | 12.53 |

Degrees of freedom; LAS: Leaf Area of Stratas; NPM: Net Photosynthesis of upper and middle stratas; PMS: Photosynthesis of upper and middle stratas; ** = Significant at 1% level, * = significant at 5% level, ns= Not significant

Table 4. Analysis table of photosynthesis Upper and middle stratas in two safflower genotypes in treatment 1⁄3 Middle leaf removal

| Source of Variation | DF | LAS | NPLS | PLS |
|---|---|---|---|---|
| Replicates | 2 | $0.00002^{ns}$ | $0.624^{ns}$ | $0.0042^{ns}$ |
| Genotyp | 1 | $0.0033^{**}$ | $1.380^{ns}$ | $0.1690^{**}$ |
| Strata | 1 | $0.0036^{**}$ | $65.754^{**}$ | $0.7998^{**}$ |
| Genotyp × strata | 1 | $0.0005^{**}$ | $2.813^{ns}$ | $0.1435^{**}$ |
| Error | 6 | 0.00003 | 1.031 | 0.0055 |
| Coefficient of Variation (%) | | 7.16 | 23.07 | 20.17 |

DF: Degrees of freedom; LAS: Leaf Area of Stratas; NPLS: Net Photosynthesis of upper and lower stratas; PLS: Photosynthesis of upper and lower stratas; ** = Significant at 1% level, * = significant at 5% level, ns= Not significant

Table 5. Analysis table of photosynthesis Upper and middle stratas in two safflower genotypes in treatment 1⁄3 upper leaf removal

| Source of Variation | DF | LAS | NPLS | PLS |
|---|---|---|---|---|
| Replicates | 2 | $0.00003^{ns}$ | $0.055^{ns}$ | $0.0005^{ns}$ |
| Genotyp | 1 | $0.0010^{**}$ | $0.036^{ns}$ | $0.0381^{**}$ |
| Strata | 1 | $0.0004^{**}$ | $123.521^{**}$ | $0.2363^{**}$ |
| Genotyp × strata | 1 | $0.000004^{ns}$ | $0.208^{ns}$ | $0.0126^{**}$ |
| Error | 6 | 0.00001 | 0.201 | 0.0003 |
| Coefficient of Variation (%) | | 5.67 | 7.35 | 5.67 |

DF: Degrees of freedom; LAS: Leaf Area of Stratas; NPLS: Net Photosynthesis of middle and lower stratas; PLS: Photosynthesis of middle and lower stratas; ** = Significant at 1% level, * = significant at 5% level, $^{ns}$= Not significant

However, in the Turnbull et al (2007) study, the nitrogen rate of these structures did not increase after defoliation. They stated that increasing photosynthesis following defoliation in the early stages causes a temporary increase in photosynthetic activity, not in photosynthetic structures. Some researchers have also reported that after defoliation, photosynthetic carbon fixation may increase in response to increased nitrogen in the remaining leaves, thereby increasing photosynthesis (Handa et al., 2005; Ozaki et al., 2004). But in general, the mechanism of increasing photosynthesis following the increase of plant nitrogen in defoliation studies has been in an aura of ambiguity, which can be a basis for further research.

According to the results in Table 4, the interaction of genotype×strata treatments in the Leaf area of strata was significant in the treatment of 1⁄3 middle leaf removal and greater values of leaf area parameter were observed in 1/3 upper strata in Mahalli İsfahan Genotyp (0.11 $m^2$) and lowest were observed in the lower 1/3 strata in Goldasht genotype (0.05 $m^2$). Genotypes did not show a significant difference in terms of Net photosynthesis but the net photosynthesis of different strata had a significant difference (P<0.01) (Table 4).

The upper 1/3 strata had more Net photosynthetic rate (6.74 µmol $CO^2.m^{-2}.s^{-1}$) and the lower strata had a lower Net photosynthetic rate (2.06 µmol $CO^2.m^{-2}.s^{-1}$) in comparison to other strata. In other words, the net photosynthesis rate of the lower strata was 69.4% less than the upper strata.

After defoliation of 1/3 middle strata, the amount of photosynthesis in the lower and upper strata compared to the control was increased by 17.5% and 34.7%, respectively. Increased photosynthesis following leaf removal has been reported in several studies (Turnbull et al, 2007; Handa et al., 2005; Elfadl and Luukkanen, 2003). The interaction of genotype×strata treatments in Photosynthesis of upper and lower Stratas after defoliation was significant in the treatment of 1⁄3 mi leaf removal (P<0.01) (Table 4). The greater values of this parameter were observed in 1/3 upper strata in Mahalli İsfahan Genotype (0.86 µmol $CO^2.m^{-2}.s^{-1}$) and the lowest was observed in the lower 1/3 strata in both genotypes. In Mahalli Isfahan and Goldasht, photosynthesis of lower strata was 76.1% and 30% less than the upper strata respectively.

Also, after defoliation, the leaf area of the remaining strata did not change compared to the control. Since defoliation treatment was applied after the plant entered the reproductive stage and the end of vegetative growth, defoliation did not affect the plant leaf area. Genotypes did not show a significant difference in terms of Net photosynthesis but the net photosynthesis of different strata had a significant difference (P<0.01) (Table 5). The Net photosynthetic rate of lower and middle 1/3 strata was 2.90 and 9.32 (µmol $CO^2.m^{-2}.s^{-1}$) respectively. In other words, the net photosynthesis rate of the lower strata was 68.9% less than the middle strata.

The interaction of genotype×strata treatments in Photosynthesis of middle and lower Stratas after defoliation was significant in the treatment of 1⁄3 upper leaf removal (P<0.01) (Table 5).

The greater values of this parameter were observed in 1/3 middle strata in Mahalli İsfahan Genotype (0.54 µmol $CO^2.m^{-2}.s^{-1}$) and the lowest was observed in the 1/3 lower strata in both genotypes. In Mahalli Isfahan and Goldasht, photosynthesis of lower strata was 63% and 59.5% less than the middle strata respectively.

After defoliation of 1/3 of upper strata, the amount of photosynthesis in the lower and middle strata compared to the control was increased by 50% and 76% in Mahalli Isfahan and 40%, 68% in Goldasht genotyp respectively.

According to the results in Table 6, the interaction of genotype×strata treatments in the leaf area of strata were significant in the treatment of the cover capitulum and greater values of this parameter was observed in 1/3 upper strata in Mahalli İsfahan Genotype (0.13 $m^2$) and the lowest

was observed in the middle 1/3 starta in Goldasht genotype (0.04 $m^2$). In the Mahalli Isfahan genotype the leaf area of the lower and middle strata were 46.2% and 53.8% and in Golshasht 28.6% and 42.8% less than the upper stratas, respectively.

Genotypes did not show a significant difference in terms of net photosynthesis but the net photosynthesis of different strata had a significant difference (P<0.01) (Table 6). The greater values of this parameter was observed in 1/3 upper strata (3.96 µmol $CO^2.m^{-2}.s^{-1}$) and lowest was observed in the lower 1/3 starta (1.79 µmol $CO^2.m^{-2}.s^{-1}$).

The interaction of genotype×strata treatments in Photosynthesis of Stratas was significant in the treatment of the cover capitulum (P<0.01) (Table 6). The greater values of this parameter were observed in the 1/3 upper strata in Mahalli İsfahan Genotype (0.50 µmol $CO^2.m^{-2}.s^{-1}$) and the lowest was observed in the 1/3 middle strata in Goldasht Genotype (0.09 µmol $CO^2.m^{-2}.s^{-1}$). photosynthesis of lower and middle strata were In Mahalli Isfahan at 78% and 68%, in Goldasht 59.3% and 66.7% less than the upper strata respectively.

Defoliation affects the process of regrowth and carbon transfer. This causes many morphological and physiological changes in the plant that may lead to changes in plant biomass. Defoliation may affect carbon stabilization capacity and plant biomass production through hormonal changes that play an important role in plant growth and development. Hormonal changes also affect the carbon and biomass stabilization capacity of plants by altering the redistribution of photosynthetic products. It has also been shown that defoliation causes the production of hydrogen peroxide and phenols as a protective mechanism in the plant. Also, removing the upper and lower leaves of the plant reduces the amount of starch and soluble sugars in the remaining leaves (Millicent et al., 2018).

According to the results in Table 7, the interactive effects between different genotypes and defoliation levels reduced significant seeds yield (P < 0.05).

Plant height was not affected by leaf removal treatment but it showed a significant difference in the studied two genotypes (P<0.01) (Table 7). The plant height of Mahalli Isfahan and Goldasht was 99.4 cm and 68.1 cm respectively. Since leaf removal was done after the end of vegetative growth, leaf removal had no effect on plant height (Abbaspour et al, 2003).

However, the highest and lowest seed yields referred to Mahalli Isfahan in control (5627 kg/h) and Goldasht next to this with 1/3 upper leaves defoliation (1310kg/h) respectively. Also, the percentage of seed yield in the Mahalli Isfahan genotype was decreasing in response to defoliation of the 1/3 lower, 1/3 middle, and 1/3 upper leaves and flag leaf as: 34%, 52%, 76.1% and 53.1% and in Goldasht genotype 12.3%, 28.2%, 76% and 42.8% in compared to the non-defoliated plants (control).

Table 6. Analysis table of photosynthesis leaf stratas in two safflower genotypes in treatment cover capitulum

| Source of Variation | DF | LAS | NPS | PS |
|---|---|---|---|---|
| Replicates | 2 | $0.00006^{ns}$ | $0.382^{ns}$ | $0.001^{ns}$ |
| Genotyp | 1 | $0.0042^{**}$ | $0.080^{ns}$ | $0.043^{**}$ |
| Strata | 2 | $0.0035^{**}$ | $7.335^{**}$ | $0.143^{**}$ |
| Genotyp × strata | 2 | $0.0008^{**}$ | $0.173^{ns}$ | $0.012^{**}$ |
| Error | 10 | 0.00004 | 0.126 | 0.001 |
| Coefficient of Variation (%) | | 9.04 | 17.121 | 11.20 |

DF: Degrees of freedom; LAS: Leaf Area of Stratas; NPS: Net Photosynthesis stratas; PS: Photosynthesis of stratas; ** = Significant at 1% level, * = significant at 5% level, $^{ns}$= Not significant

Table 7. The analysis table of effects of leaf removal from spring safflower on seed yield and yield components

| Source of Variation | DF | PH | SY | NP | NSP | NSPP | SWP |
|---|---|---|---|---|---|---|---|
| Replicates | 2 | $5.204^{ns}$ | $310104{,}033^{ns}$ | $589.0^{ns}$ | $558.17^{ns}$ | $710.1816^{ns}$ | $401.0^{**}$ |
| Genotyp | 1 | $7335.161^{**}$ | $033.2053560^{**}$ | $08.388^{**}$ | $652.428^{**}$ | $085.121158^{**}$ | $256.0^{**}$ |
| Strata | 4 | $54.895^{ns}$ | $033.14846206^{**}$ | $23.2^{ns}$ | $403.281^{**}$ | $105.46275^{**}$ | $465.0^{**}$ |
| Genotyp × strata | 4 | $67.210^{ns}$ | $033.594290^{*}$ | $217.2^{ns}$ | $793.4^{ns}$ | $377.2348^{ns}$ | $005.0^{ns}$ |
| Error | 18 | 46.727 | 367.167177 | 711.1 | 135.5 | 862.1074 | 005.0 |
| CV (%) | | 8.17 | 79.11 | 46.10 | 12.7 | 10.8 | 19.5 |

Degrees of freedom; PH: Plant High (cm); SY: Seed Yield (Kg/ha); NP: Number of pods; NSP: Number of seeds per pod (seed/pod); NSPP: Number of seeds per plant; SWP: Seeds weight per pod (g); ** = Significant at 1% level, * = significant at 5% level, $^{ns}$= Not significant

This observation indicated an important influence of upper leaves in seeds production. Ehsanzade and Mahmudieh, 2004 showed a 37% reduction in seed yield while the pods and neighbor brackets were covered in safflower plants which predominately attracted pods and neighbor leaves photosynthesis impact seeds production. Furthermore, investigators have observed a significant corresponding between upper leaves and seed yields, therefore suggesting them as the main resource more than lower leaves in sunflowers and sorghum to be more concerned about their functions (Jamshidi et al., 2008; Purahmadi et al., 2014).

According to the table 9, seed yield was significantly positively correlated with 1000 seeds weight (P<0.05), Number of seeds per plant, Biological yield, Harvest Index, and oil yield (P<0.01). With an increasing number of seeds per plant, economic yield increased, and finally, it leads to an increase in harvest index, grain yield, oil yield, and biological yield.

The number of pods and seeds per pod showed a significant difference in the studied two genotypes (P<0.01), our observation indicated a higher quantity of pods number (16/plant) and fewer number of seeds per pod (28.05 seeds/pod) in Mahalli Isfahan in compared to Goldasht with (9 pods /plant) and more seeds in a pod with 35.61 (seeds/pod) (Table 7). A similar result was found in the research of Pourghasemiyan and Zahedi, 2008 in the same genotypes. Difference morphological features like as smaller pods in the local Isfahan genotype cause fewer seeds compared to Goldasht genotype with larger pods. This factor was essentially influenced by defoliation treatment much intensively in our experiment besides the finding of a significant negative correlation (P<0.01) between seeds weight and the number of seeds per pod. This observation suggested that reduced seeds weight per pod might be happened due to the increasing quantity of pods per plant and seeds quantity in a pod which might be caused in terms of reducing photosynthesis partitioning and reducing seed weight in each pod (Table 10).

Defoliation application showed a significant negative impact on total seeds weight per pod in comparison to nondefoliated plants (P<0.01) and it was decreased orderly from 1/3 below, 1/3 middle up to 1/3 upper leaves and flag leaf: 12.5%, 14.6%, 46.9%, and 14.6% respectively (Table 7). A similar study showed a 10% reduction in seeds weight and 56.1% in seeds weight per pod in terms of covering upper leaves and flag leaf (Farid and Ehsanzadeh, 2006). Thousand seeds weigh a remarkable yield component as illustrated in table 6. This feature was higher in the Goldasht genotype (44.667g) than that in local Isfahan (27.687g). We suggested that this observation might be possibly appeared due to larger seeds size in local Isfahan which decreased seeds quantity. However, Ehsanzadeh and Zareyan, 2003 suggested that seeds' weight showed a relationship between the genotypes (Ehsanzadeh and Zareyan 2003). Defoliation treatments were influenced by total seeds weight (Table 7).

Final results indicated that defoliation treatment in the: 1/3 below, 1/3 middle, 1/3 upper leaves, and cover pods caused: 3.5%, 8.3%, 18%, and 10.5% seed weight reduction respectively in comparison with control (nondefoliated plants). Those results might be due to decreasing in photosynthesis substrates fluent for loading seeds which decreased the weight of the total seeds. Comparable studies was figured out a similar result while the middle leaves and flag leaf were cut off in safflower and decreased seed weight up to 7.7% and 6.8% respectively (Uri et al., 1968). Significant negative regression was found in the pod's quantity per plant (P<0.01) with seeds' total weight per plant (P<0.05) (Table 10). Suggesting that increasing pods number per plant might be due to reducing photosynthesis substrate fluent through the pods and eventually decreased seeds weight at the end of the experiment. Earlier studies reported that there was a significant positive regression between thousand seeds weight with seed final yield and negative regression with pods quantity per plant (Jahanbin et al., 2008).

Further results indicated a difference in thousand seeds weight throughout the investigated genotypes (P<0.01) in which Goldasht did produce 44.667g higher than that in Mahalli Isfahan with lower seeds weight of 27.687g. This might be due to appeared numerous pods in the Goldsht genotype more than in Mahalli Isfahan (Table 8). Harvest index (HI) was evaluated at the end of the study, consequently, remarkable results showed a significant effect of defoliation on HI compared with non-defoliation (Table 8). The lowest HI was illustrated in 1/3 of upper leaves defoliation in the Mahalli Isfahan genotype (10.21) whereas, lower leaves defoliation had no impact on HI suggesting that upper leaves are extremely involved in the photosynthesis process much more severely than other leaves on the plant. A similar study has noted the same observations throughout Ehsanzadeh and Mahmudieh, 2004 experiments. They have monitored photosynthesis functions on yield components while flag leaves and upper leaves defoliation reduced thousand seeds weight, number of seeds per pod, and finally harvest index. Regarding the ultimate regression between treated factors and yield compounds we find a positive significant correlation between the number of seeds per pod, seeds weight with oil produced (P<0.01), and thousand seeds weight (P<0.05). It was corresponding to a relationship between increasing numbers of seeds and therefore growing harvest index. A detailed investigation has been shown in Table 10. This finding was distinguished in the studies of Mollashahi-Javan and Dahmardeh (2009) whereas Kamali et al (2009) indicated a significant positively significant relationship between pods seed yield, number of pods per plant, harvest index and, thousand seeds weight. Two different genotypes were screened regarding oil yield stimulated to defoliation treatment (Table 8).

Further measurements demonstrated a significant difference in oil yield in the studied two genotypes with 30.53% oil production in Mahalli Isfahan compared to 23.97% in Goldasht genotype as the highest producer. This was found in the previous study carried out by Pourgasemi and Zahedi (2008)**.** Suggesting that this might be appeared to correspond with long-term growth duration in the Mahalli Isfahan genotype which allowed the plant to produce much more photosynthesis and accumulate higher seed weight in this genotype. However, defoliation showed a reverse influence on oil yield (Table 8).

Table 8. The analysis table of effects of leaf removal from spring safflower on yield components

| Source of Variation | DF | SW | HI | OP | OY |
|---|---|---|---|---|---|
| Replicates | 2 | $^{ns}2.024$ | $27.152^{ns}$ | $9.695^{**}$ | $443.702^{ns}$ |
| Genotyp | 1 | $2162.403^{**}$ | $113.335^{**}$ | $322.818^{**}$ | $40942.811^{ns}$ |
| Strata | 4 | $31.419^{**}$ | $541.970^{**}$ | $30.607^{**}$ | $1517608.893^{**}$ |
| Genotyp × strata | 4 | $^{ns}4.784$ | $95.758^{**}$ | $0.107^{ns}$ | $42026.668^{ns}$ |
| Error | 18 | 1.812 | 9.369 | 1.568 | 24112.879 |
| CV (%) | | 3.72 | 12.82 | 4.60 | 16.23 |

DF: Degrees of freedom; SW: 1000 seeds weight (g); HI: Harvest Index; OP: Oil percentage (%); OY: Oil yield (kg/ha); ** = Significant at 1% level, * = significant at 5% level, $^{ns}$= Not significant

Table 9. Correlation table of traits related to photosynthesis of different stratas

| | SYPP | NP | NSPP | NPP | SW | NP | LAS | PS |
|---|---|---|---|---|---|---|---|---|
| Seed Yield per plant | 1 | | | | | | | |
| Number of pods | 0.164$^{ns}$ | 1 | | | | | | |
| Number of seeds per plant | 0.591$^{**}$ | 0.423$^{*}$ | 1 | | | | | |
| Number of seeds per pod | 0.790$^{**}$ | 0.608$^{**}$ | 0.348$^{ns}$ | 1 | | | | |
| 1000 seeds weight (g) | 0.021$^{ns}$ | 0.904$^{**}$ | 0.246$^{ns}$ | 0.232$^{*}$ | 1 | | | |
| Net Photosynthesis | 0.075$^{ns}$ | 0.091$^{ns}$ | 0.070$^{ns}$ | 0.105$^{ns}$ | 0.103$^{ns}$ | 1 | | |
| Leaf Area of Stratas | 0.510$^{*}$ | 0.588$^{*}$ | 0.382$^{ns}$ | 0.562$^{*}$ | 0.344$^{ns}$ | 0.596$^{**}$ | 1 | |
| Photosynthesis of stratas | 0.519$^{*}$ | 0.597$^{*}$ | 0.197$^{ns}$ | 0.525$^{*}$ | 0.219$^{ns}$ | 0.852$^{**}$ | 0.921$^{**}$ | 1 |

Seed Yield per plant; NP: Number of pods; NSPP: Number of seeds per plant; NPP: Number of seeds per pod; SW: 1000 seeds weight (g); NP: Net Photosynthesis; LAS: Leaf Area of Stratas; PS: Photosynthesis of stratas; ** = Significant at 1% level, * = significant at 5% level, ns= Not significant

Table 10. Correlation table of studied traits in two safflower genotypes

| | NP | NSPP | SW | SY | BY | HI | OP | OY |
|---|---|---|---|---|---|---|---|---|
| Number of pods | 1 | | | | | | | |
| Number of seeds per plant | 0.608$^{**}$ | 1 | | | | | | |
| 1000 seeds weight (g) | 0.904$^{**}$ | 0.232$^{*}$ | 1 | | | | | |
| Seed yield | 0.134$^{ns}$ | 0.563$^{**}$ | 0.393$^{*}$ | 1 | | | | |
| Biyological yield | 0.794$^{**}$ | 0.866$^{**}$ | 0.235$^{ns}$ | 0.803$^{**}$ | 1 | | | |
| Harvest Index | 0.187$^{ns}$ | 0.454$^{*}$ | 0.367$^{*}$ | 0.803$^{**}$ | 0.172$^{ns}$ | 1 | | |
| Oil percentage | 0.776$^{**}$ | 0.857$^{**}$ | 0.673$^{**}$ | 0.303$^{ns}$ | 0.844$^{**}$ | 0.189$^{ns}$ | 1 | |
| Oil Yield | 0.080$^{ns}$ | 0.731$^{ns}$ | 0.144$^{ns}$ | 0.945$^{**}$ | 0.488$^{**}$ | 0.738$^{**}$ | 0.568$^{**}$ | 1 |

NP: Number of pods; NSPP: Number of seeds per plant; SW: 1000 seeds weight (g); SY: Seed yield; BY: Biyological yield; HI: Harvest Index; OP: Oil percentage; OY: Oil Yield; ** = Significant at 1% level, * = significant at 5% level, ns= Not significant

In the meantime, the percentage of produced oil in the plant was decreased by 8.6%, 11.9%, 19.2% and 15.7% from 1/3 below, 1/3 middle and 1/3 upper and flag leave downward in comparison to non-defoliated treatments. According to obtained data illustrated in Table 10, our findings indicated a positive significant correlation between oil production and phonologic (coleoptile and flowering stages), plant height, number of branches, number of pods, number of seeds in pod, seed yield, and biological yield. Najafi Khan Behbin et al (2020) carried a similar suggestion, and found higher yield and eventually higher oil rate in those genotypes that showed higher biological yield during growth time. He suggested that this might be affected by the number of pods and also achieves higher yield during seeds maturing in the pods. In this regard, Arbash and Baydar (2007) as well as Shafiollah et al (2000) in different studies, were suggested that the oil percentage rate was reduced in correspond with defoliation treatments during the flowering stages in sunflower plants.

Ultimately, our data indicated a significant difference between investigated two genotypes local Isfahan and Goldasht regarding oil yield percentage of 994kg/h in Mahalli Isfahan and 920 kg/h in Goldasht at the end of the growth stage. Table 8 clearly shows the negative effects of defoliation treatments on oil yield percentage with $P < 0.01$ where the lowest oil yield percentage appeared in the plants treated with 1/3 upper leaves defoliation (327.7kg/h) whereas the highest oil yield percentage has been obtained in the non-defoliated plants referred as control plants (1673kg/h) (Table 8). Final results determined a significant difference in oil yield percentages in the treated plants with 1/3 below, 1/3middle, 1/3 upper leaves and flag leaves treatments with compared nondefoliate plants as: 29.8%, 47.9%, 80.4% and 56% respectively. A positive correlation was observed with the number of seeds per pod, seeds yield, harvest index, and economic yield and, eventually oil yield rate (Table 10).

In conclusion between the two genotypes, the Mahalli Isfahan produced a higher seeds number per plant as well as a harvest index in comparison with the Goldasht genotype. In this regard, seeds number in the plant had a main role in the final yield production. This factor caused higher yield and increased seeds production in local Isfahan compared with Goldasht. Although, defoliation treatments showed a significant effect on pods dimension, seeds number in the pod, seeds number per plant, thousand seeds weight, seeds yield, harvest index, and oil yield percentage. Consequently, coving the flag leaves showed a significant negative effect on seeds yield, seeds number per pod, thousand seeds weight and, final oil yield percentage. Suggesting it happened due to photosynthesis promoting on pods and neighbor brackets obviously. Those fragments seem to be involved in final yield production in the absence of the leaves as plants' essential sources.

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